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EXPLOSIVES RESEARCH & DEVELOPMENT ESTABLISHMENT

REPORT No. 18/R/62

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by

A.C. Cleves and J.F. Sumner

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1. SUMMARY

The electrical capacitance of a number of subjects wearing insulating or conductive types of footwear on various insulating or conductive floors have been measured. The values range from 150 - 300 $\mu\mu F$ for insulated conditions to 700 - 1500 $\mu\mu F$ for conducting conditions. The effective skin resistances during electrostatic discharges from the hands and finger tips have been determined; also several measurements have been made under low-voltage continuous-current conditions. The values of resistance determined by the dynamic method are considerably smaller than those given by the low-voltage method. The results of the capacitance and resistance measurements are discussed in relation to the electrostatic hazard of handling primary explosives, and to a possible circuit equivalent to a discharging person.

2. INTRODUCTION

It is usually considered that a spark from a human is equivalent to that from a capacitor of about 400 $\mu\mu F$ discharging through a resistance of the order of 100,000 ohms. In previous reports (1,2) the incendivity of this type of spark has been shown to be comparable with those used in sensitiveness tests employing a conductive-rubber base electrode. Continuation of this work (2) has established fairly precise values for the minimum capacitance for ignition of the more important primary explosives under the test conditions. The usefulness of these values, and confidence in them, would be increased if more accurate values of human capacitance were known for a variety of conditions, e.g. type of footwear, type of floor, proximity to large earthed objects, etc. The first part of this report covers the determination of capacitance under such conditions.

Similarly it is necessary to know the effective resistance when a discharge takes place from a charged person. Qualitative agreement as regards the characteristics were obtained previously (2) for the discharge from a person and the discharge via conductive rubber. The desirability of more precise measurement of resistance was pointed out. It was also demonstrated that spark splitting could be obtained in both cases. However the interval between individual sparks must also depend on the effective resistance under discharge conditions. The second part of the report deals with these aspects.

3. CAPACITANCE MEASUREMENTS

Previous estimates of the capacitance of persons have usually been obtained by charge-sharing with a good quality capacitor. However, neither this method, nor one using a capacitance bridge, is suitable where there is appreciable leakage to earth, particularly if the leakage resistance is dependent on the applied voltage (3). A dynamic method is needed so that the effective capacitance can be determined under discharge conditions, and an oscillographic technique was adopted.

3.1 Experimental

The basic circuit is shown in Fig. 1. The person whose capacitance was being measured stood on the type of floor and wore the type of shoes under investigation. He held in one hand a brass rod electrode, 1 inch diameter and 4 inches in length. This rod was connected to the anode of

/a .....

a small thyratron CV4016 through a known resistor R_W. The anode was maintained normally at a potential of 360 volts, via a resistor R_{HT} connected to the H.T. line of a R.A.R.D.E. Mk. IIB oscilloscope. The hand electrode was also connected directly to one of the Y plates of the oscilloscope, the other plate being earthed. On closing switch S, the thyratron is fired simultaneously with the time base, and the hand electrode, together with the person holding it, discharges through R_W. The rate of discharge is determined from the oscillogram in accordance with the relationship

$$C = \frac{t}{R \times 2.303 \log_{10} (V_o/V_t)} \qquad \text{..... 1}$$

where C = capacitance in farads,

R = R_W in ohms,

V_o = initial potential at the hand electrode.

V_t = potential at the hand electrode after time t seconds.

The values of C obtained in this way also include the capacitance of the Y plate and the connection to it. This capacitance was found in a separate test to be 20 $\mu\mu F$, and this correction was subtracted from the above values of C to give the capacitances quoted. The value of R_W was chosen to be at least 20 times that of the skin in contact with the brass rod as described in Section 4.2, so that the actual value of the skin resistance, including the inevitable variations, could be neglected. In addition the value of R_{HT} had to be selected so that no appreciable recharging of the anode circuit took place during the recording of the trace (total times usually between 30 and 100 microseconds). A further resistance value had to be considered in those instances where there was appreciable leakage to earth (i.e. for the conductive shoes/conductive flooring combinations). This resistance was effectively a shunt or parallel discharge path to that through R_W. In practice, therefore, the following resistances control the potential at the hand electrode:

(a) R_{HT} controls the rate of charging of the system,

(b) R_W controls the rate of discharge (for most of the tests R_W = 40 kΩ),

(c) R_S, in series with R_W in the discharge circuit,

(d) R_F the resistance through the feet to earth, and therefore a parallel discharge circuit to R_W in series with R_S.

So that R_W can be used in the calculation for C with the minimum error, the values of all resistances must be selected so that $R_S \ll R_W \ll R_F$ and $R_W \ll R_{HT}$. With values of R_F less than about 2 megohms the 360 volt h.t. supply was insufficient to maintain a suitable potential, V, on the subject since the maximum value is given by

$$V = \frac{V_{HT} \times R_F}{R_{HT} + R_F} \qquad \text{..... 2}$$

/In .....

In order to maintain V at about 300 volts, an external source of 500 - 800 volts was used in conjunction with a reduction in the value of R_{HT} from about 5 megohms to 1 megohm. This low value of R_{HT} increased the recharging rate, but equation 1 was still sufficiently valid if the first 10 microseconds of the trace were used for the calculation. Figure 2 shows sketches of typical oscillograms for "insulating" and "conducting" conditions, the latter illustrating a longer discharge with some evidence of recharging.

The spread of results when several tests were made indicates that, where contact conditions can be satisfactorily reproduced, the accuracy of the method is better than ± 10 per cent. Tests with known capacitors, which did not involve R_S and R_F, gave values accurate to ± 3 per cent.

3.2 Effect of Size of Footwear and Size of Person

It was desirable to determine the effect of **size** of footwear in case it masked some of the effects due to variations in type of footwear and floor. Tests were confined to one floor, linoleum on gritless asphalt, using the same type of footwear, antistatic half-Wellingtons, for each person. This ensured a reasonable degree of reproducibility. The results are shown in Table 1.

TABLE 1

Effect of Size of Footwear on Capacitance of Person Standing on Linoleum Floor

Size of Half-Wellington	Capacitance, $\mu\mu F$
6	160
7	175
8	180
9	190
10	200
11	200

As expected, increasing the size of half-Wellington, i.e. increasing the area in contact with the floor, raised the capacitance. Thus a person wearing size 11 has a capacitance about 25 per cent greater than one wearing size 6. This is not a large increase and the difference in sole and heel areas in contact with the floor can account entirely for it. The size of the wearer would also have a small effect, and to differentiate between these factors one would have to test, say, a group of men of differing weights all wearing the same size shoes.

3.3 Effect of Type of Footwear and Type of Floor

The effect of type of footwear and the type of floor was determined by carrying out tests on two subjects wearing size 8 and size 9 shoes respectively. The results are summarised in Table 2 (p. 4), from which the following conclusions may be drawn.

/TABLE 2 .....

TABLE 2

Electrical Capacitances ($\mu\mu F$) of Two Subjects Wearing Different Types of Footwear on Various Insulating and Conductive Floors

Type of Flooring	Subject No. 1 Wearing Shoes, Size 8, of:				Subject No. 2 Wearing Shoes, Size 9, of:		
	Leather	Rubber	Antistatic Rubber	Conductive Rubber	Leather	Rubber	Antistatic Rubber
Linoleum	140 - 200	150	155	160	155 - 180	170	165
Linoleum near earthed cupboard	-	160	170	200	225	-	200
Dry asphalt	-	150	170	160	-	150	180
Concrete	-	140	260	290	-	205	310
Antistatic rubber	400	200	420	405	340	155	425
Conductive rubber	250 - 750	160 - 300	700 - 900	1200 - 1450	225	190 - 290	700
Copper sheet	400 - 640	210	1340	1060 - 1400	215 - 640	255	110
Galvanised iron grid	160	150	850	400 - 720	150 - 1500	170	880

/3.3.1 .....

3.3.1 The degree of conduction of the footwear, and in particular of the floor material, exerts a marked influence on the capacitance. For example, a person wearing size 8 shoes having insulating rubber composition soles has a capacitance of 150 $\mu\mu F$ on a floor of gritless asphalt covered with linoleum, and one of 300 $\mu\mu F$ on a floor of conductive rubber. The capacitance of the same person wearing conductive rubber shoes varies from 160 $\mu\mu F$ on the linoleum to about 1500 $\mu\mu F$ on a conductive rubber floor or a copper sheet connected to earth. It will be seen that the rubber shoes, whether insulating, antistatic, or conductive gave self-consistent results for the two persons. Tests with leather-soled shoes showed them to be quite variable. Since their resistance depends largely on absorbed moisture and salts, the range of values of resistance noted on many occasions is reflected also in these capacitance measurements. The table shows values for leather spanning the whole range of those for insulating and conductive footwear, the former predominating. These new results confirm the undesirability of using leather-soled shoes for antistatic purposes, though of course in this respect they are better than shoes with soles of ordinary rubber or of composition.

3.3.2 The proximity of large earthed objects has little effect. For example, the combination of rubber composition soles and linoleum gives a capacitance of 150 $\mu\mu F$ in the open laboratory as noted in Section 3.3.1, and 160 $\mu\mu F$ when standing close to a large steel cupboard connected to earth. If the person is wearing conductive footwear these values may be increased to 160 $\mu\mu F$ and 200 $\mu\mu F$ respectively.

3.3.3 A combination of footwear and floor having a total resistance greater than 1000 megohms, and therefore quite unsafe electrostatically, gives values for dynamic capacitances in the range of 150 to 300 $\mu\mu F$, this being the lower group of values as determined by the charge-sharing method. Combination of antistatic or conductive footwear with conductive floor (conductive rubber or a metal sheet) i.e. total resistance less than 10 megohms, and therefore regarded as offering protection from electrostatic hazard, gives values of 700 to 1500 $\mu\mu F$.

However, an antistatic floor, though complying with the resistance requirements using metal electrodes as in B.S. 2050, showed leakage resistances through persons in conductive footwear as high as 1000 megohms, and gave a capacitance of about 400 $\mu\mu F$ with conductive footwear. This was a floor on which such a combination gave an electrostatic potential of 60 volts on sliding the foot (3).

A galvanised iron grid (shoe scraper) which has been used in this laboratory as a localised source of leakage to earth provided a capacitance of 400 to 900 $\mu\mu F$ with conductive footwear. These lower values for conducting conditions as compared with the 700 to 1500 $\mu\mu F$ range quoted above are due to the smaller areas of contact than with flat surfaces. The small contact area gives high local pressures, and consequently comparatively low resistance paths, thus offering dual advantages from the electrostatic point of view.

3.3.4 Of two typical outdoor surfaces, concrete when dry showed capacitance of 140 - 205 $\mu\mu F$ with ordinary rubber shoes and 290 $\mu\mu F$ with conductive rubber shoes. Resistance tests on a relatively dry and clean indoor concrete surface gave leakage resistance of 6 to 12 megohms with the conductive shoes. Resistances with these shoes on dry asphalt were, however, greater than 1000 megohms, so that asphalt must be grouped with other unsafe surfaces. Concrete on the other hand appears to be relatively safe.

/4. .....

4. MEASUREMENTS OF SKIN RESISTANCE

Skin resistance can be measured in two ways (a) by a continuous-current method, or (b) by a dynamic method, i.e. using an oscillographic technique to follow a discharge. The second method is particularly valuable as it enables resistances to be measured at potentials and currents which would be fatal under the conditions of the first method. The primary interest is the resistance of the tip of the finger since this is the point at which a discharg usually takes place.

4.1 Continuous-Current Measurements

These were carried out very simply with a battery and microammeter. The left forefinger of each subject was placed in contact with a circular piece of brass, 0.8 cm^2 in area, and the right hand, moistened with potassium chloride solution, was pressed on to a brass plate of area larger than that of the hand. In this way the effect of added resistance of the right hand was minimised, and the resistance measured could be regarded as that of the left forefinger tip. Table 3 shows the results, tests being carried out at 70°F and about 40 per cent r.h. A maximum current of 1 mA. was used. Values much in excess of this are uncomfortable (4).

TABLE 3

Finger-Tip Resistances of a Number of Subjects at Different Applied Potentials (Continuous-Current Method)

Subject No.	Resistance (x 1000Ω) Measured with Applied Potential:				
	12 V	24 V	36 V	48 V	60 V
1	240	225	180	96	60
2	400	340	-	320	210
3	1200	400	-	150	68
4	400	270	-	160	-
5	150	80	45	-	-
6	150	27	-	-	-
7	300	240	90	48	-

The values should be regarded as typical and not absolute for the following reasons. Though the skin was in every case in a "normally" dry condition for that person, subsidiary tests showed that, if the person had just washed his hands, the resistance observed could be lower by a factor of about 2 for those with normally moist skin, and by a factor of about 10 for those with naturally dry skin. Minor differences were also observed according to the thickness of the skin at the person's finger-tip. The application of barrier creams, Rozalex Nos. 1, 2, 4, 5, 8 and 10, decreased the resistance by about 25 per cent, while the presence of dirt tended to increase the resistance.

From Table 3, it will be seen that Ohm's Law is not obeyed. The values, over the range where the current, I, is greater than 100 μA, can be represented b a relationship of the form

$$R = AI^{-x}$$

/where .....

where $x = 0.7$, and A is a constant depending on the personal characteristics of the skin. Similar results have been quoted by Emerson (5).

These deviations from Ohm's Law have considerable importance in relation to the electric-mains-shock hazard. However this aspect can be discussed more profitably after the high voltage measurements have been considered (see next section and Section 5).

Table 4 shows the skin resistance measured at 50 volts for the following conditions, the hand being in a "normally" dry state for each test:

(a) the left hand, holding the brass rod electrode 1 inch diameter 4 inches long, with an effective contact area of 20 cm^2;

(b) the tip of the left forefinger touching a circular brass electrode with an effective contact area of about 0.8 cm^2;

(c) the tip of the left forefinger pressing on to a gramophone needle contact with moderate pressure,

(d) the same as in (c) with light pressure.

The terms "moderate" and "light" contact have to be interpreted rather broadly, the former corresponding to a pressure just less than would pierce the outer skin. The right hand was "connected" to the circuit as before.

TABLE 4

Resistances in Ohms at Hand and Finger-Tip Electrodes Measured at 50 Volts

Subject No.	Hand, Area 20 cm^2	Finger-Tip, Area 0.8 cm^2	Needle Point	
			Moderate Contact	Light Contact
1	7×10^3	25×10^4	1×10^6	5×10^6
2	8×10^3	15×10^4	0.7×10^6	2×10^6
3	7×10^3	4×10^4	$< 0.1 \times 10^6$	0.1×10^6
4	10×10^3	22×10^4	1×10^6	2×10^6
5	5×10^3	5×10^4	0.5×10^6	5×10^6

A value of 4000 ohms has been given (6) for the resistance between two hands at 4 volts.

4.2 Dynamic-Resistance Measurements

Resistance values occurring during actual discharges from the left hand of a number of subjects were measured by a simple development of the method used for determining capacitance. The resistance R_W was omitted from the circuit so that the fall of potential on the body was controlled only by the effective skin resistance, and the capacitance of the person as determined in Section 3. Where low skin resistances appeared it was convenient to add a further capacitance of 500 $\mu\mu F$ in parallel via another brass rod electrode held in the right hand (see Fig. 3). As before, this hand was moistened with potassium chloride solution to minimise the effects of skin resistance

/between .....

between it and the brass rod, since it was at this point that the potential was indicated by the oscilloscope. A blank test showed that the time constant of this part of the circuit was of the order of 20 nanoseconds, indicating that the body potential was followed closely by this rod electrode.

The results, shown in Table 5 were determined throughout from the oscillograms at points corresponding to approximately 200 volts, for the same hand conditions as described in Section 4.1.

TABLE 5

Dynamic Resistances at the Hand and Finger-Tips of Various Subjects, in Ohms

Subject No.	Hand, Area 20 cm²	Finger-Tip, Area 0.8 cm²	Needle Point	
			Moderate Contact	Light Contact
1	430	1900	4.5×10^4	6.7×10^5
2	550	1400	7.4×10^4	6.5×10^5
3	590	1500	6.5×10^4	2.2×10^5
4	340	4400	2.1×10^4	4.4×10^5
5	490	1900	5.2×10^4	0.8×10^5

The very low resistances recorded in the second column were calculated from almost purely exponential oscillograms, showing only minor increases in resistance as the potential dropped from about 200 to 50 volts. This is in contrast to values of 5,000 to 10,000 ohms at 50 volts when measured as in Section 4.1 (Table 4). Since these low resistances might be expected to be near the value corresponding to critical damping of the circuit, depending on its self-inductance, it was thought that the oscillograms may commence as a single oscillation and become exponential as the resistance increased. An equivalent circuit was therefore made up from a ceramic capacitor discharging through a 500-ohm carbon resistor. This gave similar oscillograms to those found for column 2, and in fact oscillations were observed only when the value of the carbon resistor was less than 50 ohms, showing that the effect of self-inductance of the circuit was negligible (compare the results given in E.R.D.E. Report No. 4/R/56 (7).

The values of resistance given in column 3 are again lower than would be expected from measurements of the type described in Section 4.1 (Tables 3 and 4). The oscillograms show that the resistance rose from the values given at a potential of 200 volts, to about 5,000 ohms at 50 volts i.e. Ohm's Law was not obeyed.

4.3 Effect of Type of Socks on Capacitance and Leakage Resistance

It was found that within 2 minutes of putting on thin nylon socks and conductive shoes, the resistance to earth from the hand through the footwear and a conductive rubber floor was about 500,000 ohms. The corresponding capacitance was about 650 to 800 μμF. (This degree of conduction was also achieved within 2 minutes in the case of a lady wearing nylon stockings with size 4 conductive shoes).

The same tests when repeated with the same male subject and shoes but wearing thick woollen socks, showed resistances of 30 megohms after 2 minutes,

/and .....

and 0.6 megohm after 45 minutes. The corresponding capacitances were 640 $\mu\mu F$ and 1350 $\mu\mu F$ respectively. It appears, therefore, that with thin nylon socks which are non-absorbent, conduction is established almost immediately. On the other hand, thick woollen socks require several minutes before absorbing sufficient moisture to establish conduction. This process is accompanied by an increase in the effective capacitance.

5. DISCUSSION OF RESULTS AND THEIR RELATION TO ELECTROSTATIC HAZARDS WITH PRIMARY EXPLOSIVES

The values obtained in this report for human capacitances and resistances can now be discussed in relation to the electrostatic hazard in handling loose primary explosives. Under the conditions employed in the conductive-rubber base electrode method of spark-ignition test it has been shown that lead azide (greater than 97 per cent purity), mercury fulminate, and silver azide could only be ignited if the capacitor used in the test exceeded 400, 450, and 500 $\mu\mu F$ respectively. Table 2 shows that these values are exceeded only where there is adequate leakage to earth through footwear and floor. If fully insulating conditions were present, as would be the case with shoes having ordinary rubber or synthetic soles, on a linoleum or ordinary rubber floor, the effective capacitance i.e. 150 to 170 $\mu\mu F$ is appreciably less than the minimum capacitance for ignitions for those compounds quoted above. However it would not be safe to handle these compounds under such conditions for two reasons. Firstly, if the person is holding some object which itself has a capacitance of several hundred micromicrofarads, the total effective capacitance at the time of discharge could exceed the minimum capacitances quoted above. Secondly, it is known that lead and silver azides can be ignited by a contact type of discharge between two metals, for which the minimum capacitance for ignition is much less than the effective capacitance of the person handling them. Lead azide, for example, can be ignited with capacitances as low as 30 $\mu\mu F$ with no added resistance (2). The potential required for ignition is also not more than a few hundred volts, so that footwear and flooring must both be conductive.

With the more sensitive explosives, e.g. lead styphnate and L.D.N.R., the minimum capacitances for ignition are 20 and 40 $\mu\mu F$ respectively. All combinations of footwear and floor give capacitances exceeding these values, and thus it is essential that they are both of conductive grade.

The overall picture can be shown more strikingly if the effective capacitances, and possible electrostatic potentials as determined previously (3) are utilised to calculate the energy available, as in Table 6 (p. 10).

/TABLE 6 .....

TABLE 6

Capacitances, Potentials, and Energies due to Foot Movements of Persons in Insulating and Conductive Footwear on Insulating and Conductive Flooring

Footwear	Floor	Capacitance, C, μμF	Potential, V, Volts, on Foot Sliding	Leakage Resistance, R, Megohms	Energy, $\frac{1}{2}CV^2$, ergs
Composition	Linoleum	150	> 1,000*	> 1,000	> 750
Composition	Cond. rubber	200	> 1,000*	> 1,000	> 1,000
A/S rubber	A/S rubber	425	~ 100	500 to 1,000	21
Cond. rubber	Linoleum	160	200*	> 1,000	32
Cond. rubber	A/S rubber	405	60	1,000	7
Cond. rubber	Dry concrete	290	20*	6 to 12	0.6
Cond. rubber	Cond. rubber	1,450	2 to 10	1	0.03 to 0.7

Notes These tests were all carried out at approximately 40 per cent r.h.

*Additional measurements not included in E.R.D.E. Report No. 22/R/60 (3)

A/S = Antistatic

Cond = Conducting

The potentials acquired when the leakage paths are greater than 1,000 megohms are very dependent on several factors, including relative humidity and cleanliness. However, potentials above 1,000 volts can frequently be obtained. Sliding off a stool produces even larger potentials (3). Table 6 shows that with the larger capacitances the electrostatic potential is so small that the resultant energy is a fraction of an erg. Consequently the all-conducting state, despite the larger effective capacitance, is safe electrostatically.

The new values of skin resistance as determined under discharge conditions have a bearing on the frequency of spark splitting, on the energy dissipated from a charged person, and on the validity of the conducting-rubber base method of ignition testing.

The dynamic resistance values at 200 volts for finger-tip contact, and a hand clasping a 1-inch diameter rod, are about 2,000 ohms and 500 ohms respectively. This means that a conductive metal object held in the hand of a charged person is recharged in a few microseconds, and this is capable of giving rise to a succession of sparks to earth, the interval between them depending on the rate of approach. This was illustrated previously (2). For the case of a gaseous spark jumping from the finger of a charged person, then the operative resistance is more likely to be in the range found for needle-point contacts, i.e. say, 50,000 to 500,000 ohms, depending on the pressure exerted by the finger on the needle. Measurements of the operative resistance in the conducting-rubber base method of ignition testing gave a value of 100,000 to 250,000 ohms depending on the potential (2). Thus the resistances in practice and in the test are very similar. Moreover, it was established (7) that the proportion of energy appearing in a spark gap is independent of the circuit resistance where this is between 2,000 ohms and 3 megohms. Consequently, if the operating resistance was considerably

/lower .....

lower, as in the finger-tip case, the conducting-rubber base method is not invalidated, since the test carried out with an effective resistance of 2,000 ohms should give similar results to the normal ones of 100,000 to 250,000 ohms. This has recently been confirmed for the ignition of lead azide.

It would be very useful if a circuit equivalent to a human could be designed, so that, by simple change of some of the capacitors and resistors, all the possible variations of environment and footwear could be simulated. Various attempts were made to devise a circuit consisting of two capacitors in parallel and one in series with various leak resistors, but difficulties arose over physical representation and some of the numerical values. On the other hand, it is comparatively easy to design a circuit consisting basically of a capacitor of, say, 150 $\mu\mu F$ being fed from a larger one so that the charge on the former is maintained over a longer period of time, and thus appearing to give a discharge from an apparently larger capacitor. A capacitance measurement using a brass foil electrode inside the sock of a person wearing conductive footwear on a conductive floor gave a value of approximately 2000 $\mu\mu F$ compared with 1200 - 1450 $\mu\mu F$ as determined by a discharge from the hand. This suggests that the larger effective capacitance obtained with conducting conditions is due to the "feeding" of charge from a larger capacitance at the feet by virtue of the decreased resistance at that point, to the smaller capacitor discharging at the hand. Under insulating conditions this replenishment process is controlled by a smaller time constant, and the discharge is effectively that from a single capacitor. Since ignition hazards are only likely under these insulating conditions, corresponding to capacitances less than 300 $\mu\mu F$, the human discharge circuit is therefore adequately represented by a single capacitor discharging through a single resistor of value depending on the area of skin involved.

The resistance results are of interest in considering the question of shock from the a.c. mains supply. Since the resistance at a hand can be as low as 500 ohms (measured at 200 volts) the current could be as high as 0.5 A if there was already a low resistance path to earth. One can readily understand people being electrocuted by the mains supply if a direct earth is made for example with a wet hand on a metal pipe. If the latter situation is avoided, safety is normally assured because the person is wearing insulated shoes and stands on an insulated floor. For antistatic precautions these latter conditions are deliberately altered, and to avoid shock from the mains a lower limit of resistance is placed on antistatic floors and shoes of 50,000 ohms (B.S.2050). Thus at this limit, the current could be about 5 mA. This has been regarded as quite safe for alternating current using a hand electrode (4), but it has been found that this current is very uncomfortable if passed through the finger tip only. Usually the actual leakage resistance through shoes and floor is considerably higher than this and there is little chance of the current exceeding the lowest perceptible amount which is approximately 1 mA. However it can be seen from Table 6 that combinations of antistatic floor and antistatic shoes can give rise to stored energies of twenty ergs. This should be borne in mind when handling primary explosives and electrically initiated stores under laboratory or inspection-room conditions where antistatic materials are used rather than conductive ones, due to the possibility of mains shock. When there is little risk of the latter, then conductive flooring and shoes should be used.

6. ACKNOWLEDGEMENTS

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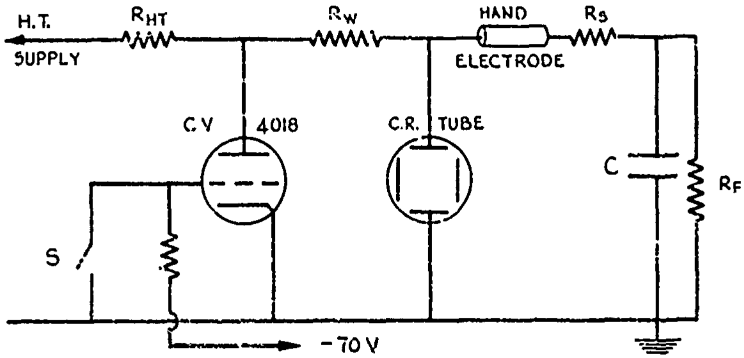
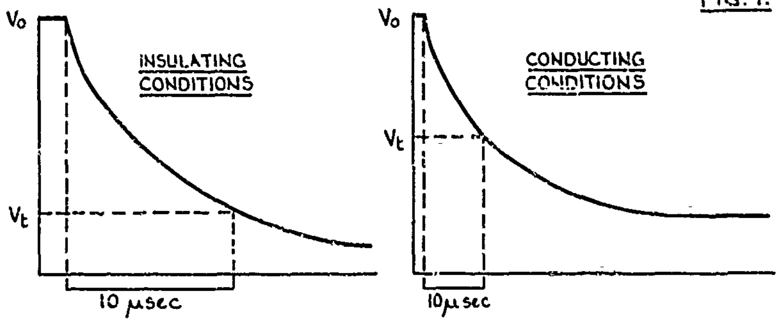


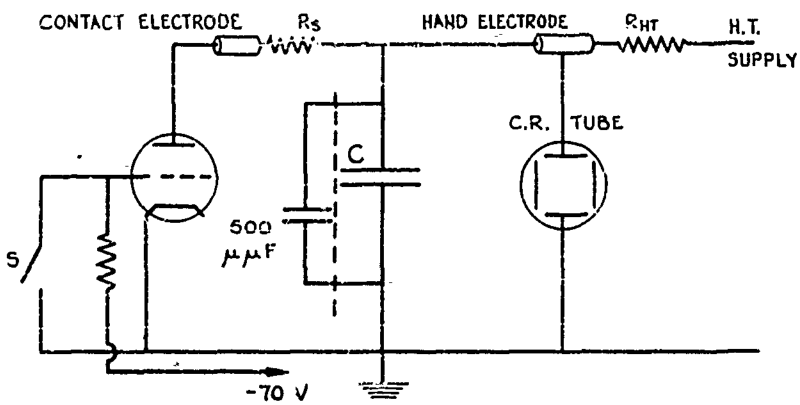
CIRCUIT FOR CAPACITANCE MEASUREMENT

FIG. 1.



TYPICAL DISCHARGE OSCILLOGRAMS

FIG. 2.



CIRCUIT FOR DYNAMIC RESISTANCE MEASUREMENT

FIG. 3.

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E.R.D.E. Report No. 18/R/62

The Measurement of Human Capacitance and Resistance in Relation to Electrostatic Hazards with Primary Explosives

A. C. Cleves and J.F. Sumner November 1962

The electrical capacitances of a number of subjects wearing insulating or conductive types of footwear on various insulating or conductive floors have been measured. The effective skin resistance, under low-voltage continuous-current conditions and during electrostatic discharges from the hands and finger tips, have been determined. The results of these measurements are discussed in relation to the electrostatic hazard with primary explosives.

12 pp., 3 fig., 6 tables

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